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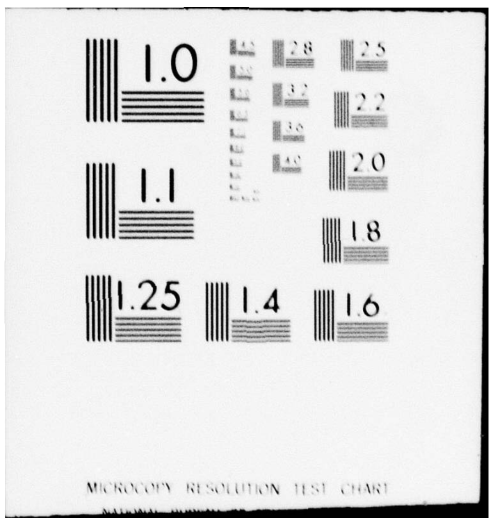
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

# METHODOLOGY FOR ASSESSING ANTENNA PERFORMANCE

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*Group 61*

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ABSTRACT

Prior to widespread use of adaptive, multiple-beam, etc., antennas in communication and radar systems, most antenna systems were relatively simple devices. Their performance could be accurately assessed by the measured antenna gain, principal plane sidelobe level, radiation impedance, and far zone polarization. In contrast, current day antenna systems can be so complex that human ability to study the measured performance data is not adequate to determine, in an objective manner, which of more than one antenna designs is superior. In addition, the large amount of data, required to assess the antenna's performance properly, is not usually put in a form suitable for appropriate assessment. In particular, visual inspection of a large number of antenna radiation pattern contour plots is realistically beyond any human's ability to quantitatively determine good performance from inadequate performance.

Clearly, today's sophisticated antenna systems require more than an adequate specification of the important performance characteristics; it is necessary to have a suitable figure of merit (FOM) that is capable of yielding an unbiased measure of the antenna systems many performance characteristics combined to yield a direct measure of their effect on the communication or radar system with which the antenna is designed to operate. This paper is addressed to the definition of such an FOM and the demonstration of its use in comparing the performance of two arbitrarily selected adaptive antennas.

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## I. FOM for an Adaptive Antenna

Usually the performance of an adaptive antenna operating in a communication system, is judged by the ratic of the directive gain ($D_d$), in the direction of the desired signal ($S_d$) source (or sources), to the directive gain ($D_u$) in the direction of the undesired signal ($S_u$) sources. The system designer needs to know the ratio $D_d/D_u$ so that he may set $S_d$ large enough to guarantee uninterrupted communication even in the presence of undesired and/or unexpected interference. Unfortunately, it is not always possible to specify the location and strength of all $S_u$; consequently, the system designer might consider the "worst case" performance characteristics in specifying the antenna's performance. This could lead to an antenna system much too large, too complicated, or perhaps even impractical. Hence the system designer must compromise, or trade-off, the system performance. He might do this by specifying the antennas performance on a statistical basis; that is, $D_d/D_u > X$ for Y% of the communication system's operating hours. In short an intelligent quantitative means of trading off system performance characteristics must be provided.

In response to the foregoing, let us consider an FOM which consists of first dividing the antenna's angular field of view (FOV) into a grid of cells as indicated in Figure 1. Next select a particular location and strength of desired and undesired signal sources (i.e., an $S_d$-$S_u$ scenario) and "allow" the adaptive antenna under test to adapt. Next the directive gain* is determined at each cell in the FOV. Then the cells are grouped according to their angular (or other) separation from the undesired signal sources. For example, Zone 1 might include all cells within 1° of an undesired signal source. Zone 2 would include all cells between 1° and 3° from $S_u$; Zone 3 would include all cells more than 3° from $S_u$. The values of directive gain would be sorted in accordance with their associated zone. In the case of more than one $S_u$, a cell may be in more than one zone. In this case, the cell would be assigned to the zone closest to an undesired signal source.

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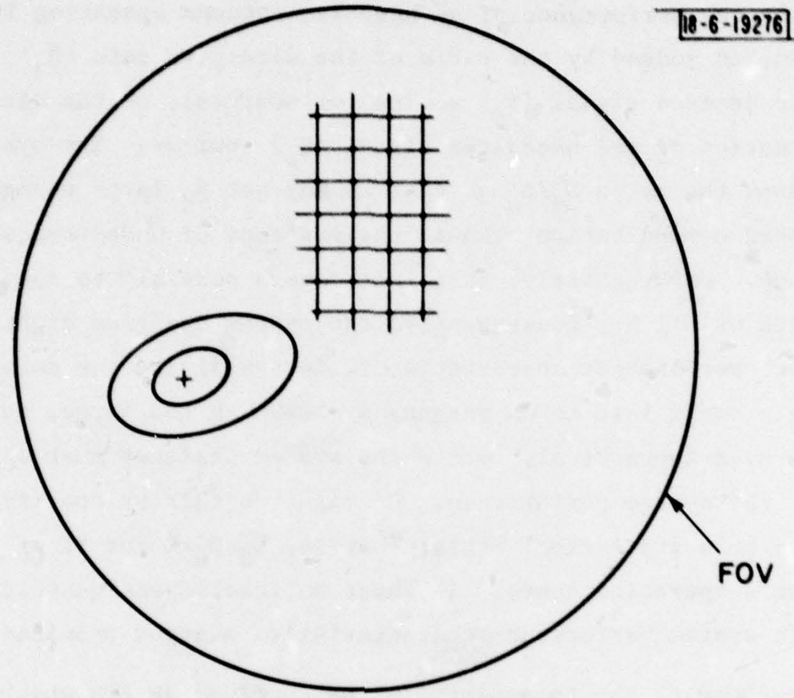
*Since the antenna is receiving signals, the antenna's receiving cross section A is required. However, for reciprocal antenna (as is almost always true), $D=4\pi A/\lambda^2$; hence D will be used throughout this note instead of receiving cross section.




MULTIPLE UNDESIRED SOURCES

$$D_U^{\circ} = \frac{\Sigma D_U P_U}{\Sigma P_U}$$

SORT ACCORDING TO:

ANGULAR SEPARATION
OR DISTANCE SEPARATION

YIELD

$$P\left(D_D/D_U > x\right) \text{ vs } x$$

$$P\left(D_D > x\right) \text{ vs } x$$

Fig. 1. Figure of merit.

Next a new $S_d$-$S_u$ scenario is selected, the antenna is allowed to adapt, and the directive gain is determined and sorted as described in the foregoing paragraph. This procedure is repeated until all important $S_d$-$S_u$ scenarios have been considered, or a data base, sufficient for statistical analysis, has been accumulated. Using this data base, one can determine the probability of realizing $D_d/D_u$, greater than a selected value, in any of the zones. Of course, the worst and best results could be presented in those cases where the designer wishes to achieve a certain "guaranteed" performance.

In those instances when the strength of the undesired signal strength is known, the ratio $D_d/D_u$ can be used to determine the effective radiated power (ERP) required by the desired signal source to overcome that signal radiated by the undesired signal source. The results of this calculation could be presented as a statistical distribution; that is, what ERP is required for $S_u/S_d \geq A$ with probability X. In those cases where more than one interfering source of different intensity is present, one could determine an effective $D_u$ (i.e., $D_u^\circ$) in accordance with

$$D_u^\circ = \left(\sum_{i=1}^{I} D_i P_i\right) / \left(\sum_{i=1}^{I} P_i\right) \tag{1}$$

## II. Illustrative Example of an FOM

In order to demonstrate the utility of the proposed FOM, let us consider the following two adaptive antennas (see Figure 2):

1. A hexagonal planar array of seven identical 8 dB gain antennas with an interelement spacing equal to 1 meter.

2. Same array as in 1 but with an interelement spacing equal to 4 meters.

We will assume each antenna has the same adaptive algorithm and must operate at 450 MHz, in the presence of two undesired signal sources each in any one of 25 different locations. The desired signal sources are assumed to be anywhere in the FOV. We are in fact attempting to determine the interelement spacing

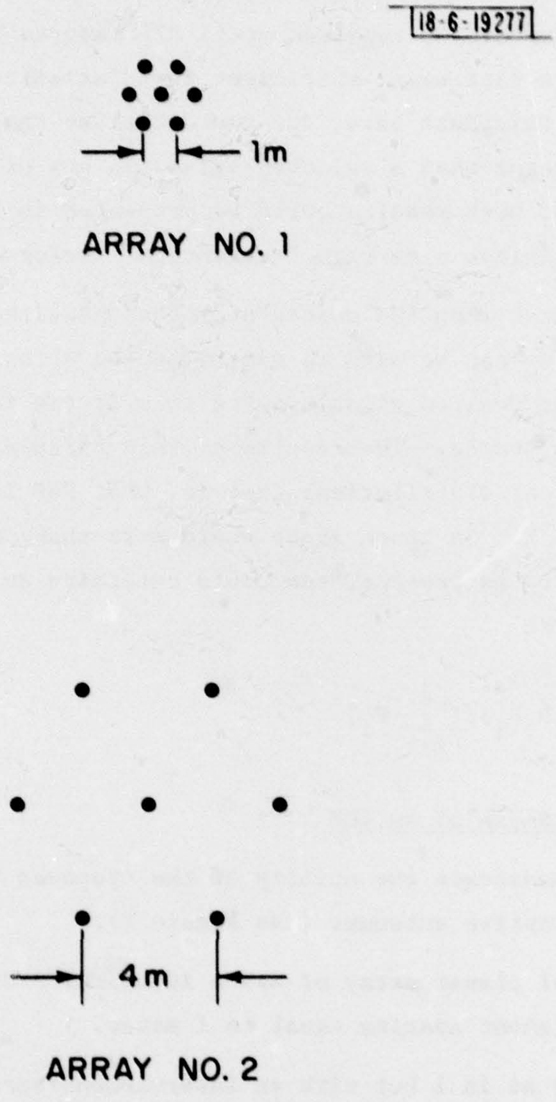



Fig. 2. Array antenna configurations.

best suited to this particular set of twenty five $S_d$-$S_u$ scenarios with all other antenna design parameters held constant. All values of directive gain will be determined analytically assuming phasing and matching errors appropriate to limit the depth of null to a credible value. In order to demonstrate the utility of the FOM, two pairs (one for each array) of radiation contour plots associated with two specific $S_d$-$S_u$ scenarios will be presented. Some conclusions will be conjectured, and then the FOM resulting from all 25 scenarios will be presented.

With the antennas fully adapted to a particular scenario, the antennas' directive gain at all cells in the FOV was calculated. The resulting antenna radiation pattern contour plots for array 1 and array 2 are shown in Figures 3 and 4. The location of the interfering sources is indicated by a large solid dot on each plot. The FOV is centered on the antenna's broadside direction and subtends an angle of 17.3°. The system designer (in our present analysis) must assume that the desired signal sources could be located anywhere in the FOV as indicated by the edge of the contour plot.

These results are not too different than one would have expected; that is,

1. The smaller array has a smooth radiation pattern with null centered on each interfering source.

2. The large array provides an irregular, uneven coverage of the FOV but the null on each undesired source is sharper and lesser in extent than that of the smaller array.

3. The larger array produces a larger directivity (i.e., 12.8 dBi vs 8.8 dBi).

In short, the larger antenna aperture provides increased resolution of the desired nulls but introduces extra nulls because the interelement spacing is large enough to produce "grating" lobes and nulls within the FOV. The point of this comparison, however, is that should 0 dBi directive gain be adequate, it is not immediately obvious which antenna gives the best coverage of the FOV.

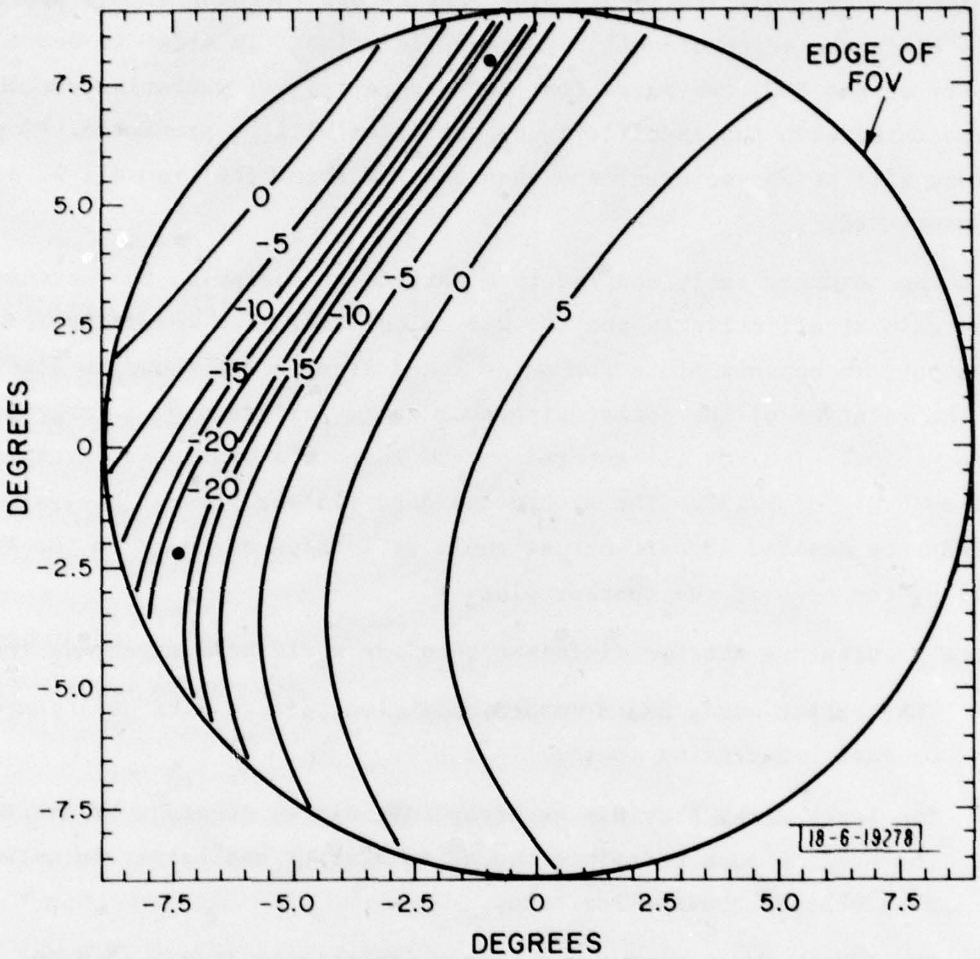



Fig. 3. Directive gain (element spac. = lm).

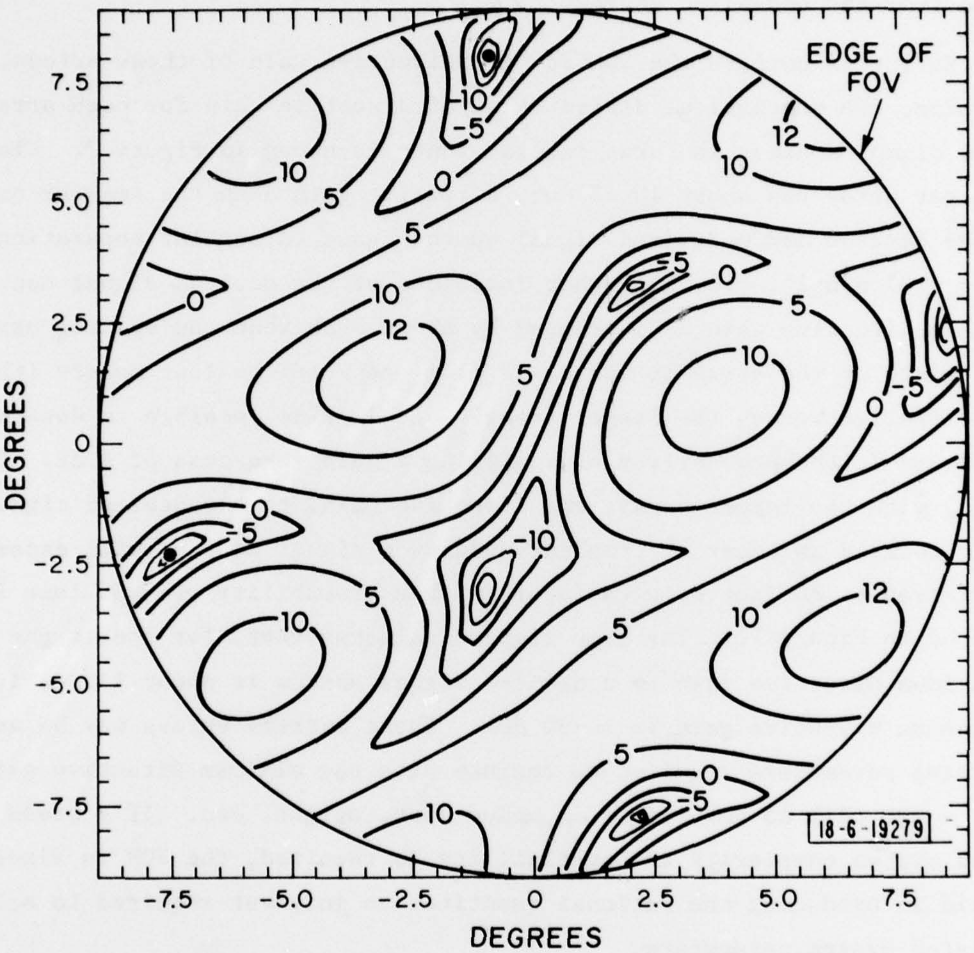



Fig. 4. Directive gain (element spac. = 4m).

The choice of which antenna is best becomes further confused when we compare similar results (Figures 5 and 6) obtained with a different location of the undesired sources. In this latter case, the smaller array appears to give superior results in that the larger array has at least six extra nulls far removed from the undesired sources.

Next let us compare the FOM for the directive gain of these arrays. In particular, the statistical distribution of directive gain for each array with desired signal sources in three angular zones is shown in Figure 7. Clearly the larger array has about 10 dB more directive gain than the smaller array when the desired and undesired signal sources have an angular separation between 0.5° and 2°. For all other locations of the desired signal source, the antenna's directive gain is increased by about 5 dB when the spacing between the elements of the array is increased from one meter to four meters (that is, for the smaller versus the larger array). It is also possible to determine, from Figure 7, the probability of realizing a gain in excess of A dB. For example, with the larger array, the directive gain, to the desired signal sources located at least 2° from any undesired signal source, will exceed 5 dBi (dB referred to an isotropic radiator) with a probability of 0.56 (see lines indicated in Figure 7.) The same figure indicates that, for the larger array, the maximum directive gain to a desired signal source is about 13.5 dBi, and the minimum directive gain is $\approx -30$ dBi. These extreme values may be useful if the system parameters required to operate with the minimum directive gain (i.e., $\approx -30$ dBi) do not result in undue cost, weight, etc. If a trade off between system complexity and availability is required, the FOM in Figure 7 will aid in producing the rational quantitative judgment required to select the associated system parameters.

The ratio $D_d/D_u$ may also be of prime importance in determining those antenna parameters best suited to the desired system performance. The radiation contour plots shown in Figures 3-6 do not give this information directly. However, it can be calculated from the same data base used to complete these figures. The probability of a desired signal source realizing $D_d/D_u \geq A$ is

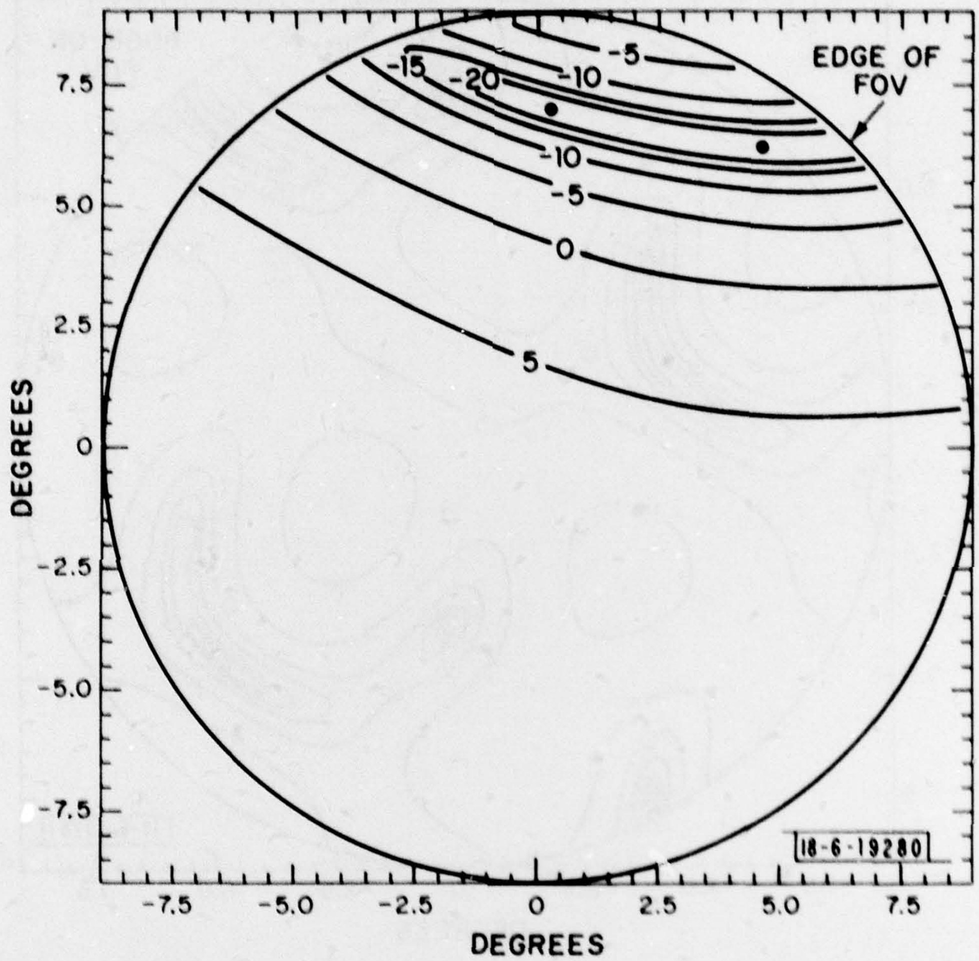



Fig. 5. Directive gain (element spac. = 1m).

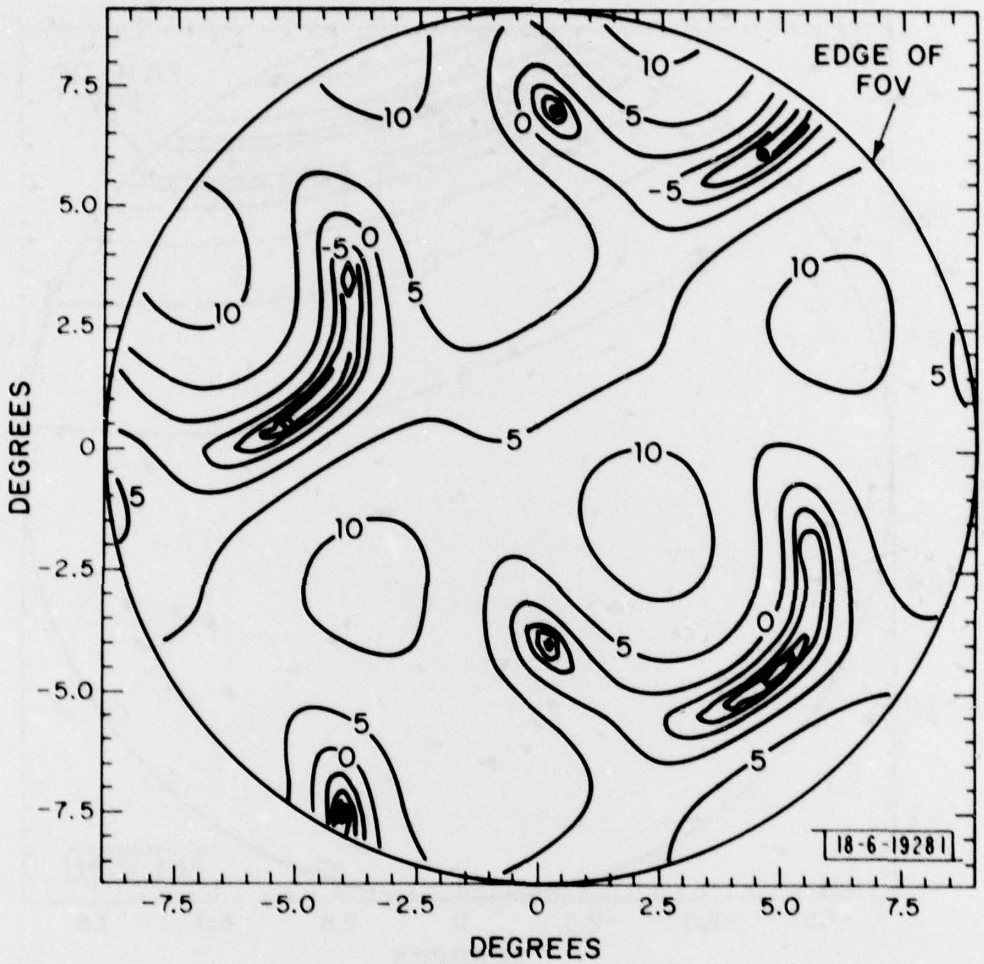



Fig. 6. Directive gain (element spac. = 4m).

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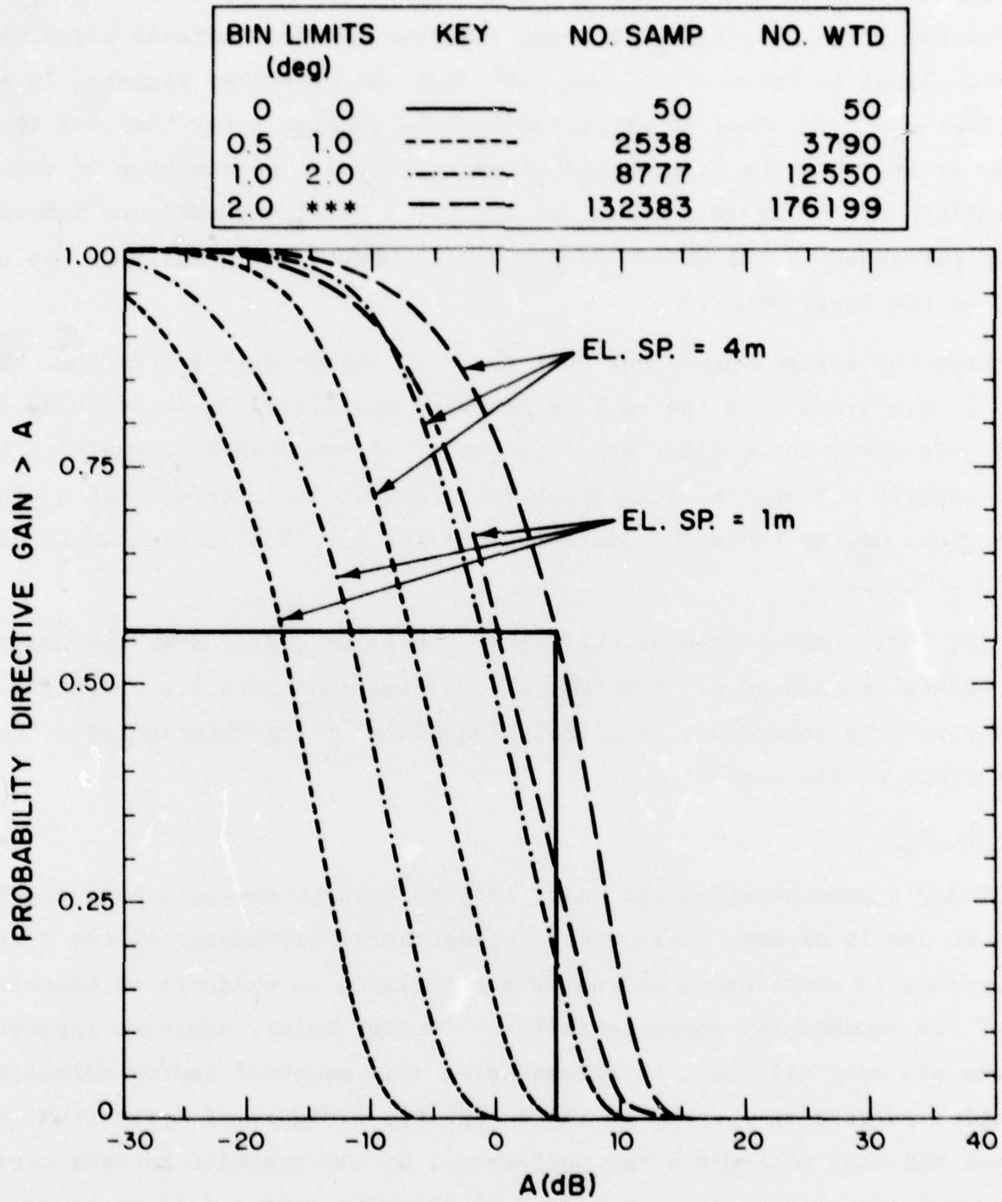


Fig. 7. Directive gain FOM.

plotted in Figure 8 for both the small and the large arrays. This FOM can be used in the same manner as that shown in Figure 7. Notice that, for events with probability >0.5, $D_d/D_u$ is about the same for each antenna array when the desired signal is between 0.5° and 2.0° from the undesired signal. It is also true that $D_d/D_u$ is about 10 dB better for the smaller array than for the larger array, when the desired and undesired signal sources have an angular separation >2.0°! These conclusions are not intuitively obvious; however, they can be explained by the smooth as opposed to uneven radiation patterns of the small vs the large array.

From the foregoing, we see that this FOM analysis indicates that the large array is preferred over the smaller array if maximizing $D_d$ is of prime importance. However, the smaller array is better if one wishes to maximize $D_d/D_u$. These results are not intuitively obvious, and it is doubtful that a visual inspection, of the radiation contour plots for all 25 scenarios would yield the same conclusions.

The "NO. SAMP" listed at the top of the figures indicates the number of data points in each zone. The "NO. WTD" listed indicates the weighting of these points in accordance with their individual representation of a "cell" on the surface of the earth.

## III. Summary

Today's communication and radar systems have become much more complex than those in use 15 or more years ago. Consequently, assessment of the system performance is complicated and not readily placed in evidence by measuring a few of its fundamental characteristics. In particular, adaptive antenna systems are very difficult to assess using only measured and/or calculated radiation pattern contours. In the foregoing, a figure of merit (FOM) was defined and used to compare the performance of two adaptive antenna arrays. Both arrays consisted of seven 8 dB gain elements arranged in an hexagonal grid on a plane surface. They differed only in their interelement spacing; it was one meter for the smaller array and four meters for the larger array. Both arrays operated at 450 MHz, and they were subjected to 25 identical undesired

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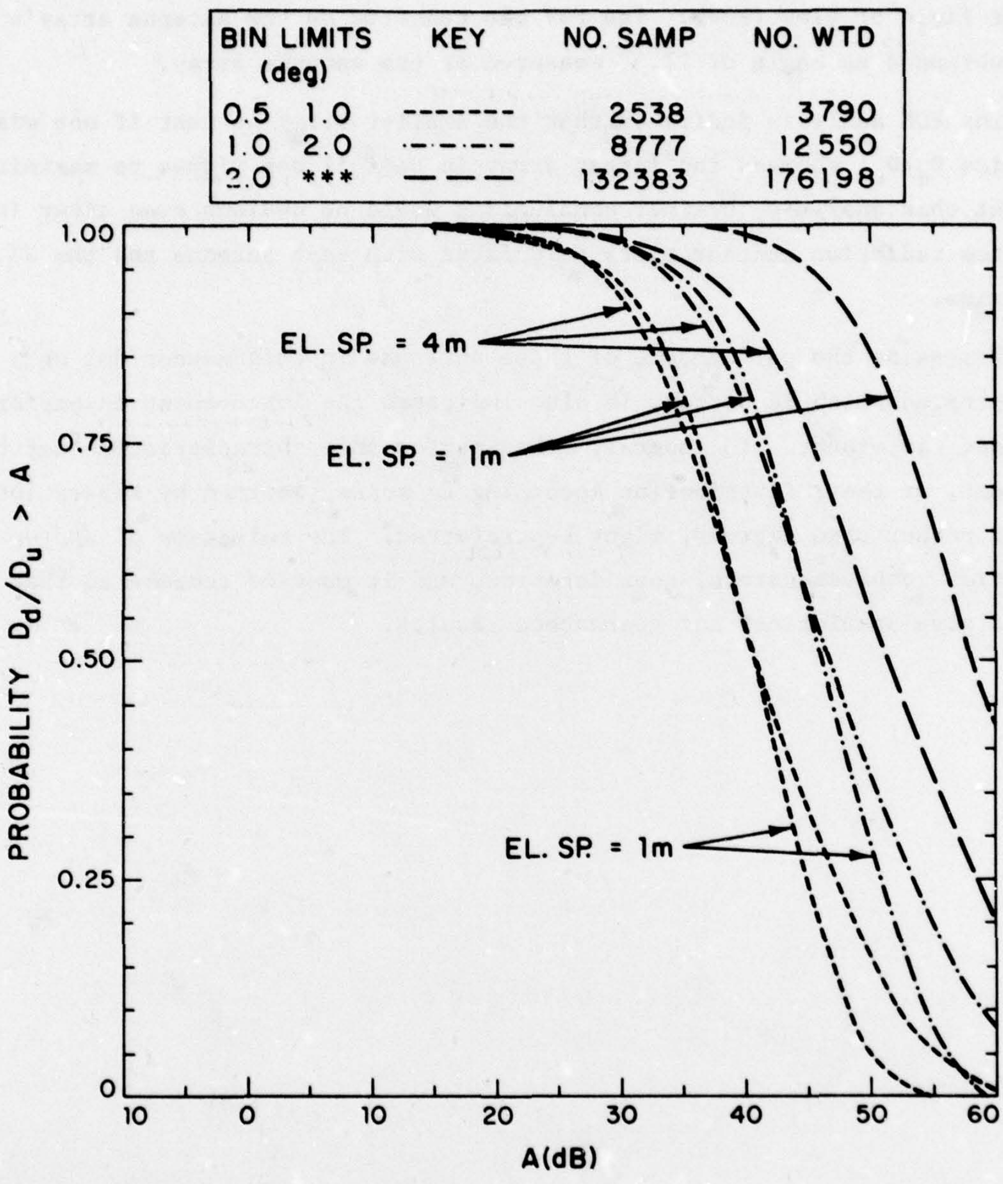


Fig. 8. $D_u/D_d$ FOM.

signal source scenarios; the desired signal sources were assumed to be anywhere in the field of view (FOV). The FOV was centered on the antenna array's axis and subtended an angle of 17.3° measured at the antenna array.

The FOM analysis indicates that the smaller array is best if one wishes to maximize $D_d/D_u$; whereas the larger array is best if one wishes to maximize $D_d$. Without this analysis, neither conclusions would be obvious even after inspecting the radiation contour plots associated with each antenna and the 25 scenarios.

Assessing the performance of these antennas in this manner not only demonstrated which is better, it also indicates the improvement in performance that one can expect. In general, other performance characteristics may be of interest, or their distribution according to zones, defined by separation in miles, rather than degrees, might be preferred. The selection of appropriate scenarios requires careful consideration, and it must be remembered that these curves give statistical not guaranteed results.

**Acknowledgments**

The author is indebted to friends and colleagues whose discussions, comments, and corrections led to the use of the FOM analysis described here. In particular, he is indebted to Dr. A. Horvath for his help in defining an appropriate FOM and to Drs. J. T. Mayhan and A. J. Simmons for their guidance in interpreting some of the results. The calculated results shown in this paper were obtained by Mr. H. Weiner using a program designed and written by Dr. M. L. Burrows.

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Prior to widespread use of adaptive, multiple-beam, etc., antennas in communication and radar systems, most antenna systems were relatively simple devices. Their performance could be accurately assessed by the measured antenna gain, principal plane sidelobe level, radiation impedance, and far zone polarization. In contrast, current day antenna systems can be so complex that human ability to study the measured performance data is not adequate to determine, in an objective manner, which of more than one antenna designs is superior. In addition, the large amount of data, required to assess the antenna's performance properly, is not usually put in a form suitable for appropriate assessment. In particular, visual inspection of a large number of antenna radiation pattern contour plots is realistically beyond any human's ability to quantitatively determine good performance from inadequate performance.

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